# The meteoroid environment enhancement at Mars due to Comet C/2013 A1 (Siding Spring)


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On October 19, 2014, Comet C/2013 A1 (Siding Spring) will pass within 120,000 km of Mars.

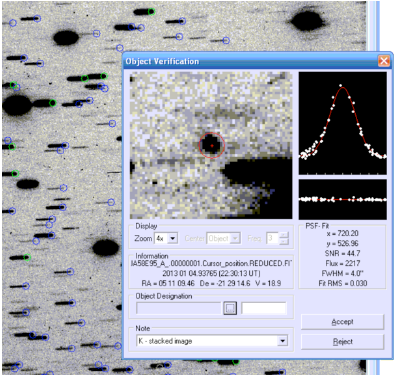
This is closer than all known Earth-comet encounters.

A collision has been ruled out, but Mars and its manmade satellites will pass through the coma and tail.

Mars will be showered with meteors and satellites will have an increased risk of meteoroid impacts.

# Outline

# C/2013 A1 (Siding Spring)




- Discovery:
  - January 3, 2013
  - Rob McNaught
  - 0.5 meter telescope
  - Siding Spring, Australia
- Pre-discovery images located in Catalina Sky Survey
  - Active in earliest images (Dec. 8, 2012)
- Hyperbolic orbit

# C/2013 A1 (Siding Spring)

- Mars fly-by on Oct. 19, 2014, 18:45 UTC ($\pm$ 0:37).
- Will approach Mars head-on from south of the orbital plane (retrograde orbit, $i = 129^\circ$)

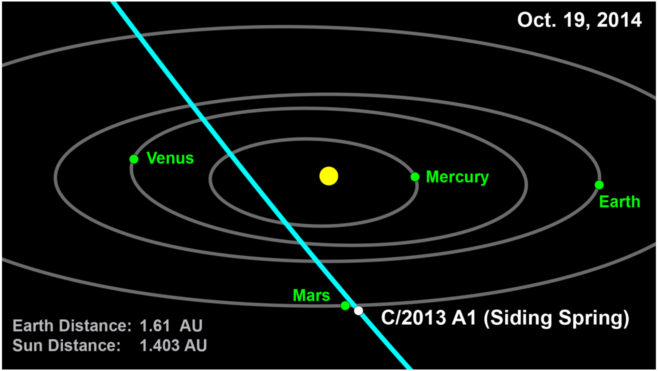
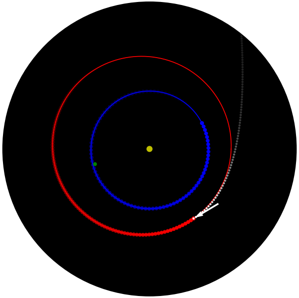


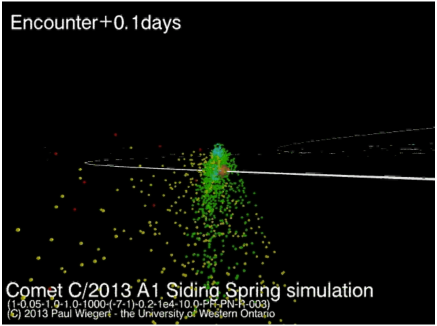

Image by [JPL NEO]

# Close Encounter with Mars
## Details




- Close approach distance is 119,000 km
- Relative speed is 56 km/s
- Visible from Earth, Stereo-B
- Reaches minimum distance from Sun (1.4 AU) on Oct. 25, 2014, a few days after Mars encounter

# Close Encounter with Mars




Movie by Dr. Paul Wiegert, UWO

- Comet is north of Mars's orbital plane at closest approach
- Close approach: 30,000 - 260,000 km
- Approach distance nominal value: 119,000 km
- Coma/tail will envelop Mars

# Particles in the Coma and Tail of Siding Spring


- Coma and tail contains both gas and particles
- Both grow as heliocentric distance decreases
- Fluence – flux integrated over Mars/spacecraft trajectory
  - Direct measure of spacecraft risk
- We compute the particle fluence at Mars using properties of Siding Spring (magnitude, orbit), supplementing with Halley data (particle albedo, size distribution) where necessary.

# The Giotto Flyby of 1P/Halley

- We have detailed coma data for one comet: Halley.
- Giotto recorded 12,000 impacts.
- Model fits to these data yield:
  - Particle density and albedo
  - Particle size distribution
  - Particle spatial distribution
- Total number of particles derived from Siding Spring magnitude, not Halley.

# Estimating the Meteoroid Enhancement

Quantifying the number of 100 micron[1] or larger particles in the coma/tail:

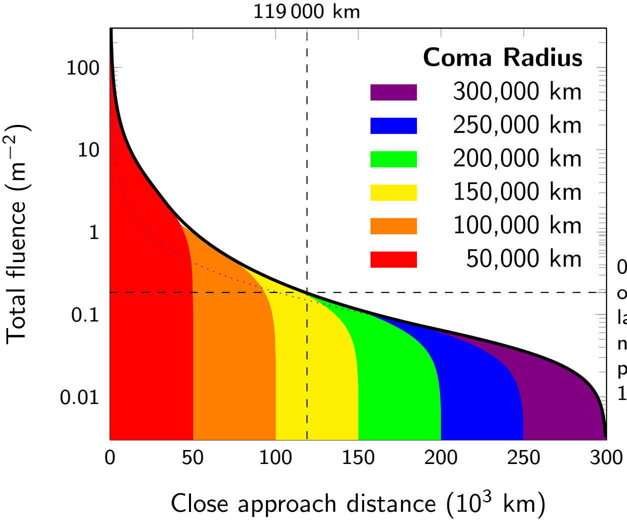
1. Determine the brightness at the time of the encounter.
2. Use a typical particle albedo (reflectivity) to compute the total particle surface area.
3. Combine with Halley-like particle size distribution and material density to compute the number of particles.
4. Use a standard spatial distribution to compute the number density.
5. Integrate along the trajectory to get fluence.

Our analytic model can be used to quickly calculate new fluence estimates as comet properties are measured/constrained.

[1] 100 micron particles are capable of cutting exposed spacecraft wires

# Analytic Model

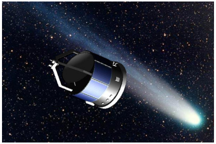
## Fluence depends strongly on close approach distance

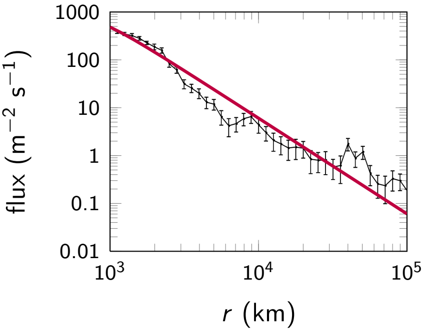



0.185 $m^{-2}$ fluence of 100 micron or larger particles at nominal close approach distance of 119 000 km

# Validation #1: Reproducing Giotto Results

- We test our model by applying it to 1P/Halley
- Using a coma radius of 200,000 km, we can reproduce the flux Giotto recorded

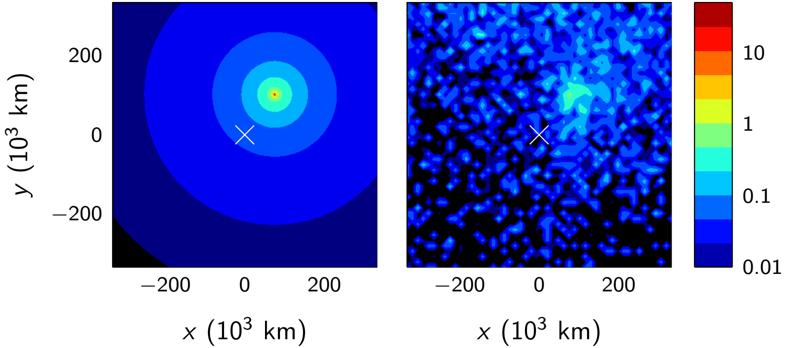





Fulle et al. (2000) data, our model

# Validation #2: Comparison with Simulations

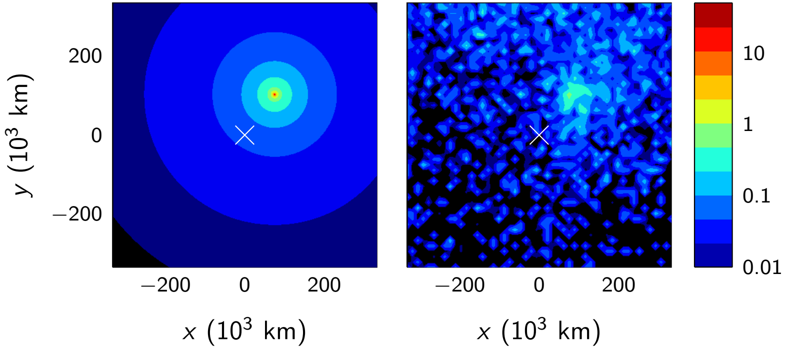
## 100 + $\mu$m particles




- Analytical model (left) and normalized simulations (right) in plane containing Mars (at origin), perpendicular to trajectory.
- Simulations performed by Dr. Paul Wiegert, UWO.

# Validation #2: Comparison with Simulations

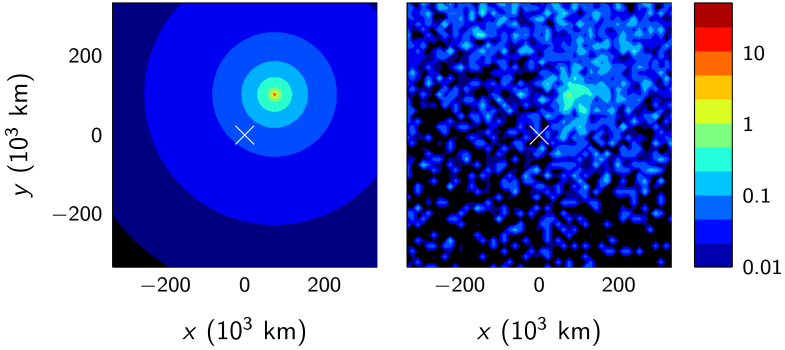
## $100+\mu$m particles




- Small scale simulations do not predict number of particles; fluence on right is multiplied by $N_{theory}/N_{sim}$.
- Simulations *do* illustrate (modest) deviance from spherical model due to coma asymmetry and tail.

# Validation #2: Comparison with Simulations

## $100+\mu$m particles

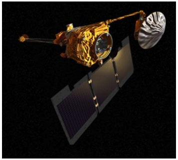



- Simulated coma has large radius ($800,000$ km) due to early assumed start of activity (10 AU)
- Distributing particles over a larger area to match simulations lowers the fluence at Mars
- Effective radius may be smaller – needs further study

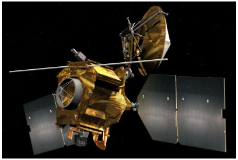
# Additional Validation

- Parallel efforts to fully model coma particle dynamics are in progress (Dr. Paul Weigert, UWO, Dr. Jeremie Vaubaillon, Paris Observatory)
  - These models will derive a fluence estimate from an assumed production rate.
  - Will provide additional check on analytic model.
- Future observations may constrain $Af\rho$
  - $Af\rho =$ Albedo $\times$ filling factor $\times$ coma radius
  - Quantifies solids in coma
- We will continue to rely on analytic models to recalculate fluence as Siding Spring's properties are measured/constrained.

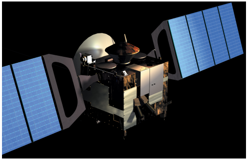
# Mars Satellites



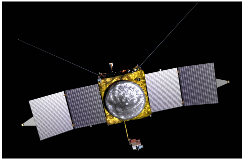
Mars Odyssey (NASA)
400 km, 2 hour orbit



Mars Recon Orbiter (NASA)
300 km, 2 hour orbit

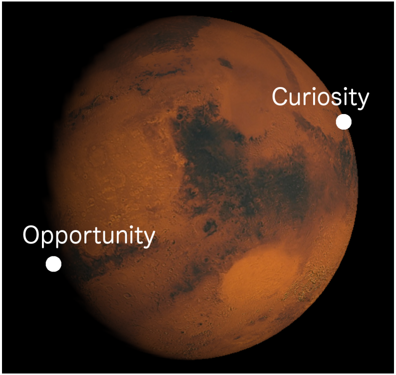


Mars Express (ESA)
300 - 10,000 km, 7.5 hour orbit



MAVEN (NASA)
150 - 6,200 km, 4.5 hours
Arrives September 2014

# Martian Meteor Shower




- Meteor shower will accompany Siding Spring
- Zenithal hourly rate (ZHr) $\sim$ 40,000 at Mars
- Lasts a few hours, may be observable from Opportunity
- Subradiant location:
  - Near Opportunity
  - Timing close to local dawn

# Meteoroid Impact Risks

## Comparison with typical risk

1966 Leonids by A. Scott Murrell

- Average flux of 100 micron or larger meteoroids in low Earth orbit is $5 \times 10^{-6}$ m$^{-2}$ per hour
- Fluence due to Siding Spring is 10,000 times higher (5 years of LEO exposure)
- There has never been an event like this near Earth in recent memory, with the possible exception of the 1966 Leonids.

# Meteoroid Impact Risks

- Impacts to critical components
- Sudden attitude changes
- Electrostatic discharges (ESDs) possible at high velocities, but local spacecraft environment and charging state must be taken into account
- Siding Spring meteor stream most similar in speed to Perseids at Earth
- Two spacecraft anomalies attributed to Perseids:
  - Landsat 5 lost attitude control during 2009 Perseids
  - OLYMPUS satellite lost during 1993 Perseids
    (More info: McDonnell et al., 1993, Caswell et al., 1995)

# Possible Mitigation Strategies

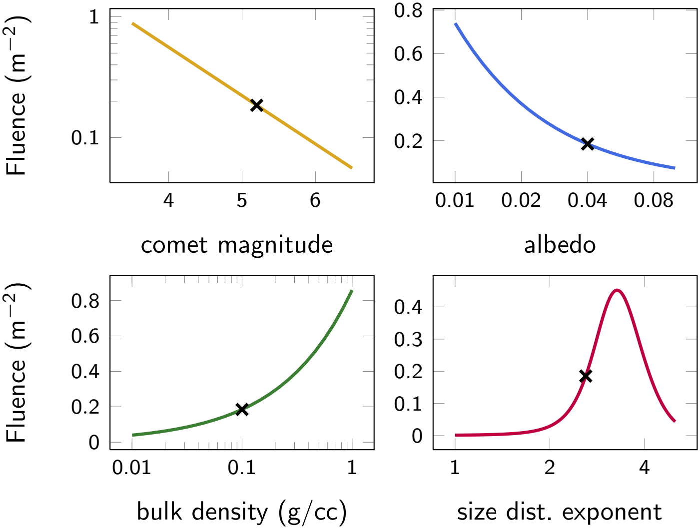
- Align solar arrays sunward, edge-on to meteor shower
  - Sun-Mars-comet angle is $90.2^\circ$
- Present hard side to radiant
- Phase orbit to use Mars as a partial shield:
  - Depends on orbit geometry
  - Shower will last a few hours, dependent on coma size (30 min per 100,000 km of coma/tail)
  - Odyssey and MRO have 2 hour orbits

# Summary

- Comet C/2013 A1 (Siding Spring) will have close encounter with Mars on October 19, 2014
- Mars and spacecraft will pass through coma and tail containing meteoroids
- Meteoroids (100 $\mu$m or larger): $\sim$ 20% chance of impact per square meter due to coma and tail
- This risk is 10,000 times higher than equivalent time exposure in LEO.

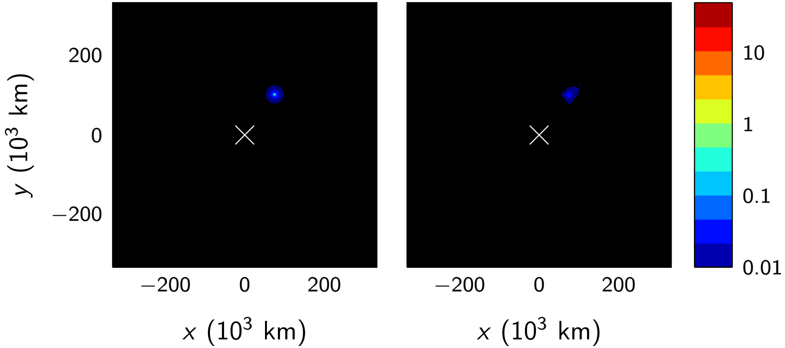
# Analytic Model

## Dependence on comet/meteoroid properties



# Comparison with Simulations: Very Large Particles

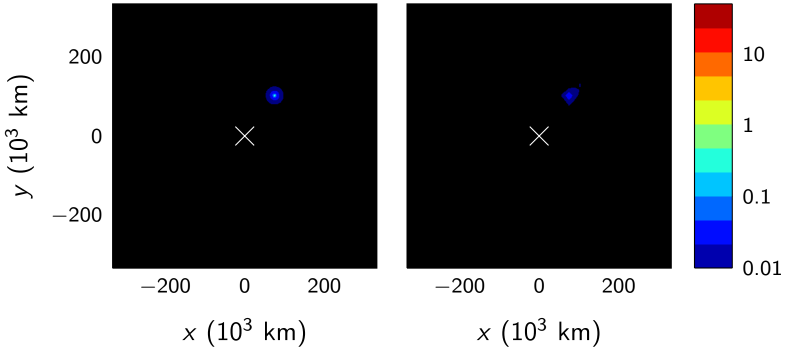
## $> 1000 + \mu$m




- Larger particles ($s > 1000\ \mu$m) are much less numerous due to inverse power law size distribution

# Comparison with Simulations: Very Large Particles

$> 1000 + \mu$m




- Larger particles ($s > 1000$ $\mu$m) stay closer to the nucleus:
  - Lower ejection velocity
  - Less subject to radiative forces